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Aluminium and Calcium – Key Factors Determining the Survival of Vendace Embryos and Larvae in Post-mining Lakes?

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With 2 Figures and 2 Tables

Key words: Post-mining lakes, acid tolerance, calcium, aluminium, *Coregonus albula*, early life stages

Abstract

After decommissioning of many open-cast lignite mines, numerous acidic post-mining lakes have formed in the Lusatian district (eastern Germany). With regard to (1) plans for neutralisation and subsequent use of these lakes for fisheries and (2) the risk of reacidification of previously neutralised lakes, the effects of acidic post-mining lake water on fish are of major interest. In order to investigate the contribution of Al to overall toxicity and to assess whether the high Ca content of the lakes has a protective effect, early life stages of vendace, *Coregonus albula*, were exposed for 60 days to nine combinations of pH, Al and Ca in reconstituted post-mining lake water. Low pH (pH 4.75 and 5.00) associated with 1.0–1.1 mg l^{-1} Mn and 0.1 mg l^{-1} Fe did not reduce hatching success and survival during the embryonic and early larval development when the Al concentration was low (0.1–0.2 mg l^{-1}). However, when the Al content was increased to 2.4 and 2.1 mg l^{-1} at pH 4.75 and 5.00, respectively, mortality prior to hatch was high, no (pH 4.75) or very few embryos (pH 5.00) hatched, and no fish survived to the end of the experiment. Increasing the Ca concentration from 111–117 mg l^{-1} to 233–256 mg l^{-1} had no influence on hatching and survival percentages. Thus, the deleterious effect of the high Al concentrations (2.4 and 2.1 mg l^{-1}) was greater than the protective effect of the high Ca content.

Introduction

In the Lusatian district (eastern Germany), large-scale open-cast mining of lignite has resulted in the formation of a severely disturbed landscape containing numerous artificial lakes. As a consequence of weathering of iron sulphides, these lakes typically have pH-values of about 3.0 and are rich in Fe and SO_4^{2-} (GELLER et al. 1998; NIXDORF et al. 1998a, b). Furthermore, concentrations of Ca, Al, Mn and, frequently, trace metals are increased due to geochemical mobilisation (REICHEL & UHLMANN 1995; FRIESE et al. 1998).

For neutralisation purposes, some post-mining lakes have been flooded with circumneutral river water. Plans for future utilisation of the lakes include fisheries (KLAPPER et al. 1998). In most post-mining lakes, littoral zones covered with macrophytes are scarce. Therefore, vendace (*Coregonus albula* L.), a pelagic species using zooplankton as food resource (JACOBSEN 1982), appears to be appropriate for stocking and some aged, neutralised post-mining lakes have already been stocked with vendace. As previously neutralised lakes may reacidify, for example during periods with reduced supply of river water (REICHEL & UHLMANN 1995; HEMM et al. 1999), the effects of acidic post-mining lake water on fish are of prime interest.

In surface waters affected by acid rain, high mortalities of embryos and larvae are the major cause for the decline of fish populations (PETERSON et al. 1982; OVERREIN 1983; SAYER et al. 1993). Acid tolerance does not only vary with species, strain and life stage, but greatly depends on hydrochemical conditions. In soft acid water, Al and Ca are the major factors influencing the sensitivity of fish to acidification. Elevated concentrations of inorganic monomeric Al (Al_{im}) exacerbate the toxic effects of low pH-values on fish (PLAYLE et al. 1989; LYDERSEN et al. 1990; ROSSELAND & HENRIKSEN 1990). The embryonic stages prior to hatch are, however, less sensitive to Al than eleutheroembryos and larvae, and Al concentrations below 0.3–0.5 mg l^{-1} may even have a protective effect on survival to hatch (BAKER & SCHOFIELD 1982; INGERSOLL et al. 1990; SAYER et al. 1991). Apart from Al, increased concentrations of Mn, Fe and trace metals also have a deleterious effect on fish (READER et al. 1988, 1989; NYBERG et al. 1995), whereas elevated Ca concentrations mitigate the toxicity of low pH, Al and Mn (BROWN 1982; READER et al. 1988; POTTS & MCWILLIAMS 1989; STUBBLEFIELD et al. 1997). Increased levels of Mg, Na and K also have a protective effect, although to a lesser extent than Ca (RASK 1984; HUTCHINSON et al. 1989).

Compared to the extremely dilute fresh waters affected by acid rain, concentrations of all ions are greatly increased in the Lusatian post-mining lakes. On the one hand, Ca levels in the post-mining lakes (typically 100–400 mg l^{-1}; REICHEL & UHLMANN 1995; NIXDORF et al. 1998b) are much higher than those in soft acid waters (usually below 3 mg l^{-1}; GJESSING et al. 1976; SPRY & WIENER 1991; SAYER et al. 1993). On the other hand, Al concentrations in acidic post-mining lakes are typically in the range of 1–10 mg l^{-1} (KLAPPER & SCHULTZE 1995; FRIESE et al. 1998; NIXDORF et al. 1998b), whereas those in soft acid waters rarely exceed 0.5 mg l^{-1} (GJESSING et al. 1976; SAYER et al. 1993; HOWELLS et al. 1994). In addition, concentrations of Fe and Mn in the post-mining lakes are high (KLAPPER & SCHULTZE 1995; FRIESE et al. 1998; GELLER et al. 1998). Precipitation of ferric hydroxide on eggs may reduce survival of fish embryos (SMITH et al. 1973; GEERTZ-HANSEN & RASMUSSEN 1994).

In a previous study (DUIS & OBEREMM 2000), early life stages of vendace were exposed to reconstituted post-mining lake water in order to assess the critical pH for survival under the hydrochemical conditions typical for Lusatian post-mining lakes. High mortalities were observed at pH ≤5.00 before, during and shortly after hatch and at pH 5.50 well after the onset of exogenous nutrition.

The aims of the present study were (1) to determine the contribution of the high Al concentrations to the overall toxicity of moderately acidic (pH 4.75 and 5.00) reconstituted post-mining lake water to embryonic and early larval stages of vendace and (2) to assess whether the high Ca levels in the reconstituted post-mining lake water have a protective effect on early development of vendace exposed to pH 4.75 and 5.00.

Materials and Methods

Experimental media

Early life stages of vendace were exposed to nine combinations of pH, Al and Ca in reconstituted post-mining lake water (Table 1). The elevated Al and Ca concentrations were in the range of those found in Lusatian post-mining lakes (KLAPPER & SCHULTZE 1995; REICHEL & UHLMANN 1995; FRIESE et al. 1998; NIXDORF et al. 1998b), whereas the lower Al and Ca levels corresponded to those in the neutral river water used for flooding (D. LESSMANN, pers. comm.).

The experimental media were prepared as follows. First, reconstituted hard, acidic water (pH 3.30, conductivity 917 µS cm^{-1}) and reconstituted neutral water (pH 7.40, conductivity 643 µS cm^{-1}) were prepared by addition of sulphuric acid and inorganic salt solutions to deionised water. Apart from the levels of Al and Ca, which were reduced, the composition of the hard, acidic water was based upon the concentrations of major inorganic constituents measured in Lake Gräbendorf, Lower Lusatia (D. LESSMANN, pers. comm.; see also NIXDORF et al. 1998b), a typical recently formed post-mining lake (HEMM et al. 1999). Nominal (= added) concentrations in the acidic water (mg l^{-1}) were Na: 10; K: 4; Ca: 120; Mg: 25; Fe: 10; Al: 0.3; Mn: 2; Cl^-: 25; SO_4^{2-}: 384. Reconstituted neutral water was prepared according to the hydrochemical characteristics of the river water which is, for neutralisation purposes, diverted into Lake Gräbendorf (D. LESSMANN, pers. comm.). It contained the following nominal concentrations (mg l^{-1}): Na: 20; K: 7; Ca: 91; Mg: 13; Fe: 1.5; Al: 0.3; Mn: 0.5; Cl^-: 36; SO_4^{2-}: 241; HCO_3^-: 64. The media were mixed using circulation pumps and aerated overnight. Then, test solutions with pH 4.75 and 5.00 (four tanks, A–D, for each pH) were prepared by mixing acidic and neutral water. Finally, the Al concentrations in tanks A and B were increased by addition of 2.4 and 2.2 mg l^{-1} Al at pH 4.75 and 5.00, respectively. The Ca concentrations in tanks A and C were increased to double of those in tanks B and D (see Table 1). Prior to using them in the early life stage test, the test solutions were aerated for at least three days. The pH-values were measured daily (WTW model 526 pH meter) and, if necessary, readjusted by addition of acidic (pH 3.30) or neutral (pH 7.40) medium as required.

Due to the pH-dependent solubility of Al, the measured concentrations of Al, which are presented in Table 1, were slightly lower than nominal (= total added) concentrations. Since both Al and Ca were added as sulphates, the SO_4^{2-} concentrations of the test solutions increased slightly with elevated Al content and markedly with elevated Ca levels. Conductivity also increased with increasing Ca content. There was little variation in the concentrations of Na, K, Mg, Fe, Mn and Cl^- (Table 1). Precipitation of ferric hydroxide occurred in all test solutions and, consequently, the measured Fe concentrations were below the nominal concentrations. Supernatant water was used for incubation of the fish.

Chemical analysis

The test solutions were filtered (0.45 µm cellulose-acetate filters, Sartorius) and analysed according to German standard methods (DEV 1986–1998; for the measuring fault see ZWIRNMANN et al. 1999). Concentrations of Na and K were measured by atomic emission spectrometry, those of Ca, Mg, Mn and total dissolved Al by flame atomic absorption spectrometry (Perkin-Elmer AAS 3300). Al concentrations below 0.2 mg l^{-1} were determined by graphite furnace atomic absorption spectrometry (Perkin-Elmer HGA 600). Concentrations of Cl^- and SO_4^{2-} were measured by ion chromatography (Sykam), dissolved Fe was quantified using the ortho-phenanthroline method.

Early life stage test

Since vendace from the circumneutral Lake Arendsee (Sachsen-Anhalt, Germany) were used for stocking of some neutralised post-mining lakes, we used fish from the same origin for our study. Chemical characteristics (mean values from 0–20 m depth for 1997) of Lake Arendsee were: Na: 22.6; K: 9.7; Ca: 63; Mg: 8.6; Fe: <0.03; Cl^-: 44; SO_4^{2-}: 75 mg l^{-1}; conductivity: 491 µS cm^{-1} (H. RÖNICKE, pers. comm.). Mature spawners were caught on January 7, 1998 (day 0) at a water temperature of 5 °C and a pH of 7.79. Ova and sperm were obtained by stripping the fish immediately after capture. The eggs were inseminated in lake water and transferred to the experimental media after 1.5 h. Reconstituted neutral water (pH 7.40) was used for incubation of the controls. The eggs were incubated in polystyrene Petri dishes (Greiner, 89 mm diameter) containing 20 ml of test solution. All treatments were carried out in quadruplicate with 40 eggs per replicate. Until the onset of hatching (day 50) test solutions were renewed every other day, thereafter daily. The pH-values of the new test solutions were readjusted to the nominal pH (= target pH) of the

Table 1. Measured hydrochemical characteristics of the test solutions used in the early life stage test: means ± SD (n = 5) for conductivity (µS cm^{-1}) and single measurements for the concentrations of dissolved Al, Ca, Na, K, Mg, Fe, Mn, Cl^- and SO_4^{2-} (mg l^{-1}).

Nominal pH, treatment	Specific conductivity	**Al**	**Ca**	Na	K	Mg	Fe	Mn	Cl^-	SO_4^{2-}
pH 4.75 A	1004 ± 157	**2.4**	**256**	16.9	6.4	18.7	0.11	1.11	32	538
B	715 ± 74	**2.4**	**115**	16.9	6.5	18.2	0.06	1.10	30.	324
C	1008 ± 153	**0.2**	**254**	16.9	6.3	18.8	0.10	1.02	32	554
D	707 ± 71	**0.2**	**117**	17.0	6.4	18.2	0.11	1.09	34	340
pH 5.00 A	998 ± 147	**2.1**	**239**	16.6	6.3	17.9	0.07	1.04	35	544
B	707 ± 71	**2.1**	**112**	16.5	6.4	17.6	0.09	1.05	34	326
C	990 ± 144	**0.1**	**233**	16.3	6.3	18.2	0.07	1.01	32	536
D	701 ± 70	**0.1**	**111**	16.1	6.2	18.1	0.09	1.06	32	312
pH 7.40	643 ± 45	**0.1**	**106**	19.7	7.2	13.0	0.06	0.47	35	230

respective treatment if necessary, and the pH-values of the old (= removed) solutions were measured. During the 24 or 48 h interval between two replacements of the test solutions in Petri dishes, pH-values of the acidic solutions tended to increase. In the treatments with elevated Al concentrations these changes in pH were relatively small, but at lower Al content they increased, especially during the period of hatching and after the onset of feeding. Both at nominal pH 4.75 and 5.00, measured pH-values of the old test solutions in treatments C and D were about 0.2–0.3 pH-units higher than those in treatments A and B (Table 2). As an approximation of the average pH during exposure, mean values of the nominal pH (i.e. the pH to which the new test solutions added to the Petri dishes had been adjusted) and the measured pH of the old, removed solutions were calculated for each treatment and day. Calculations were performed on the concentrations of H^+ and converted to pH. At both nominal pH-values, the calculated average pH-values in treatments C and D were about 0.1 pH-unit higher than those in treatments A and B. Calculated average pH-values in the treatments 4.75A–D were significantly lower than those in the corresponding treatments at pH 5.00 (4.75A vs. 5.00A, 4.75B vs. 5.00B etc.; see Table 2). For the sake of clarity, nominal pH-values are used throughout the text.

Table 2. The pH-values of the test solutions used in the early life stage test: nominal pH (= pH of the new test solutions), measured pH of the old, removed test solutions[1]), and calculated average treatment pH-values[1]).

Nominal pH, treatment		Measured pH of removed test solutions	Calculated average treatment pH
pH 4.75	A	4.91 (4.89–4.93)	4.82 (4.81–4.83) [e]
	B	4.81 (4.70–4.95)	4.78 (4.73–4.84) [e]
	C	5.08 (5.02–5.16)	4.89 (4.86–4.91) [d]
	D	5.10 (5.04–5.19)	4.89 (4.87–4.92) [d]
pH 5.00	A	5.08 (5.06–5.10)	5.04 (5.03–5.05) [c]
	B	5.05 (5.04–5.07)	5.03 (5.02–5.03) [c]
	C	5.32 (5.24–5.42)	5.13 (5.11–5.16) [b]
	D	5.35 (5.27–5.45)	5.14 (5.11–5.17) [b]
pH 7.40		7.21 (7.12–7.32)	7.29 (7.24–7.36) [a]

[1]) Mean values and 95% confidence limits.
[a–e]) Calculated average treatment pH-values followed by a different letter are significantly different from each other (ANOVA, Dunnet-T3, $p < 0.05$).

Early life stages of vendace were incubated at 6 °C until day 6, then temperature was gradually increased to 9 °C (7 °C until day 7, 8 °C until day 56, 9 °C until day 60) in order to imitate the seasonal increase in water temperature. Fish were fed *ad libitum* with cultured *Paramecium caudatum* and newly hatched *Artemia* nauplii (AF 480, INVE Aquaculture).

Mortality of vendace was registered daily. Unfertilised eggs, i.e. eggs which either had no perivitelline space or which showed abnormal cleavages during very early stages (Fredrich 1980; Shields et al. 1997), and malformed embryos and larvae were removed and counted as dead ones. The number of fully hatched embryos was recorded daily, embryos which died in a partly hatched state were registered separately. Mortality prior to hatch, hatching mortality, hatching and survival to the end of the experiment were expressed as percentages of the number of eggs at the beginning of exposure. The experiment was terminated on day 60, a few days after the onset of exogenous nutrition.

The terminology of Balon (1975) was used for the early life stages, with first feeding marking the transition from the embryonic to the larval period. The term 'eleutheroembryo' is applied to the last embryonic phase (from hatching to first feeding).

Statistical analyses

Percentages of unfertilised eggs, hatching and overall survival were arcsine-square root transformed and analysed by one-way ANOVA followed by the Tukey test. When analysing hatching percentages and overall survival, treatments with 100% mortality and no hatch were excluded from ANOVA, since differences were obvious and homogeneity of variances would have been offended. Calculated average treatment pH-values were compared by one-way ANOVA followed by the Dunnet-T3 test, which is appropriate in case of heteroscedasticity. All tests were performed at the 5% level of significance using the SPSS statistical program.

Results

In all treatments, ferric hydroxide was precipitating on the egg envelopes. Interestingly, the amount of precipitate on the eggs exposed to pH 4.75 and 5.00 was low when the Al concentration was elevated (treatments A, B), whereas it was fairly large when the Al content was reduced (treatments C, D). There was very little precipitate on the eggs incubated at pH 7.40 (control).

In the control, mortality prior to hatch was 41%. Unfertilised eggs (33%) which were removed during the first days of the experiment accounted for most of this background mortality. As expected (all eggs were inseminated in circumneutral lake water), there were no significant differences between the percentages of unfertilised eggs in any of the treatments.

Survival from fertilisation to hatch was strongly affected by elevated Al levels. In the treatments with high Al concentrations (2.4 mg l^{-1} in the treatments 4.75A and B, 2.1 mg l^{-1} in the treatments 5.00A and B), mortality started to increase on day 35, two weeks prior to the onset of hatching at pH 7.40, and reached values between 90 and 98%. 3 and 2% of the embryos in the treatments 4.75A and B, respectively, died in a partly hatched state, yet no embryos successfully completed the hatching process (Fig. 1). At pH 5.00 and 2.1 mg l^{-1} Al, hatching began 5–7 days later than in the control. The hatching percentages were extremely low (1% in treatment 5.00A, 5% in treatment 5.00B, see Fig. 1), and the eleutheroembryos did not survive longer than a few days. Two percent of the embryos in treatment 5.00A and 5% in treatment 5.00B died after partial hatching.

By contrast, survival from fertilisation to hatch and hatching percentages (see Fig. 1) at pH 4.75 and 5.00 did not differ significantly from control values when the Al concentration was low (0.2 mg l^{-1} in the treatments 4.75C and D, 0.1 mg l^{-1} in the treatments 5.00C and D). In these treatments, there was either little (4.75C: 1%) or no hatching mortality (4.75D, 5.00C and D).

During the last few days of the exposure, the larvae kept at pH 7.40 and those in the treatments 5.00C and D were feeding regularly on *Paramecium* and on *Artemia* nauplii, whereas most larvae in the treatments 4.75C and D were only ingesting *Paramecium*. In Fig. 2, survival of vendace to the end of the experiment (day 60) is presented. There was no survival in the treatments with Al concentrations of 2.1 and 2.4 mg l^{-1} (4.75A and B, 5.00A and B). However, exposure to pH 4.75 and 5.00 did not significantly reduce survival of vendace to day 60 when the Al concentration was 0.1–0.2 mg l^{-1} (4.75C and D, 5.00C and D).

When comparing the treatments which did not differ in their Al content, but were characterised by different Ca levels (4.75A vs. B, 4.75C vs. D, 5.00A vs. B and 5.00C vs. D; see Table 1), it can be seen that increasing the Ca concentration from 111–117 mg l^{-1} to 233–256 mg l^{-1} had no significant influence on hatching percentages (Fig. 1) and survival to the end of the experiment (Fig. 2).

Discussion

In order to determine the contribution of Al to total toxicity and to assess whether the high Ca levels have a protective effect, embryonic and early larval stages of vendace were exposed to several combinations of pH, Al and Ca in reconstituted post-mining lake water. Due to the relatively high temperature in January 1998, the end of the spawning season of vendace in Lake Arendsee was reached shortly after the experiment was started. The elevated percentage of unfertilised eggs, which accounted for most of the high background mortality, was probably related to this fact. It has been shown that as a consequence of overripening of the eggs, the fertilisation rate may decrease during the last phase of spawning (WILKONSKA & ZUROMSKA 1981; KAMLER 1992).

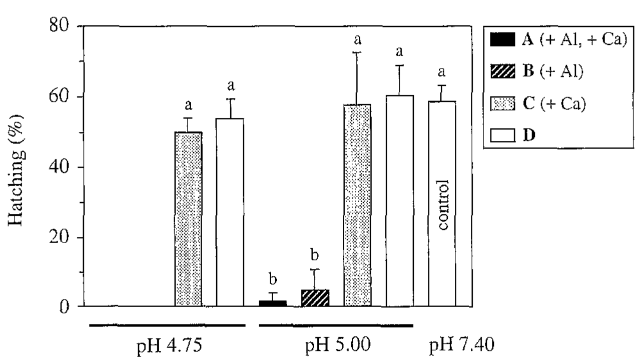

Fig. 1. Hatching percentages of vendace embryos (mean values ± SD). Percentages marked with 'a' differ significantly from those marked with 'b' (ANOVA, Tukey, $p < 0.05$). In the treatments 4.75A and 4.75B, no embryos hatched.

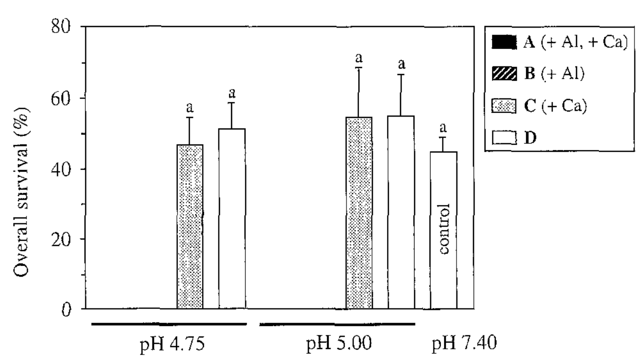

Fig 2. Percent survival of vendace at the end of the experiment (day 60): percentages (mean values ± SD) refer to the number of eggs at the beginning of exposure. In the treatments with elevated Al content (A and B), there were no survivors. Survival percentages in the treatments with low Al content (C and D) were not significantly different from those at pH 7.40 (ANOVA, Tukey).

Despite this background mortality, the results of the experiment were very clear. Low pH (pH 4.75 and 5.00) associated with Mn levels of 1.0–1.1 mg l^{-1} and Fe concentrations of about 0.1 mg l^{-1} did not affect survival during the embryonic and early larval development when the Al content was low (0.1–0.2 mg l^{-1}). However, when the Al concentration was increased to 2.4 and 2.1 mg l^{-1} at pH 4.75 and 5.00, respectively, survival of vendace from fertilisation to hatch and hatching percentages were severely affected and no fish survived to the end of the experiment.

In soft acid water (pH 4.5 and 5.4), Mn concentrations of 0.36 and 1.08 mg l^{-1} had a detrimental effect on Ca uptake and skeletal calcification in brown trout *(Salmo trutta)* eleutheroembryos. These negative effects of Mn were, however, minor compared to those of 0.16–0.22 mg l^{-1} Al (READER et al. 1988), which is in the range of the lower Al level in our study. Furthermore, increasing the Ca content from 1 to 20 mg l^{-1} provided a good protection against Mn toxicity (READER et al. 1988). Accordingly, the high Ca content of the experimental media might also have antagonised the toxicity of Mn in our study.

It is not clear in which way precipitation of ferric hydroxide on vendace eggs was reduced by the high Al content. Anyhow, since significant amounts of Fe hydroxide were only observed on the eggs when the Al concentration was low and survival in these treatments did not differ significantly from control values, the effects of Fe precipitates on development of vendace from fertilisation to hatch appear to be minor. Concentrations of dissolved Fe in all treatments were clearly below 0.5–1.0 mg l^{-1}, the level considered to be critical for survival of brown trout embryos (GEERTZ-HANSEN & RASMUSSEN 1994). In our experiment, formation of thick layers of precipitate on the eggs, which might cause suffocation of the embryo (SMITH et al. 1973; GEERTZ-HANSEN & RASMUSSEN 1994), was prevented, because vendace eggs were moved during the replacements of the test solutions. In view of the fact that in streams receiving acid mine drainage, deposits of ferric hydroxide have a major adverse effect on benthic invertebrates (JARVIS & YOUNGER 1997) and may smother fish eggs (HOEHN & SIZEMORE 1977), it should, however, be considered that accumulation of Fe on the egg surface might also affect survival of fish embryos in the post-mining lakes.

Compared to Al levels in soft acid waters (SAYER et al. 1993; HOWELLS et al. 1994), the elevated Al concentrations in our study (2.1 and 2.4 mg l^{-1}) were very high. The toxicity of Al is dependent on its speciation, which in turn depends on pH, concentrations of complexing ligands, ionic strength and temperature (LYDERSEN et al. 1990; HERRMANN & BAUMGARTNER 1992). Inorganic monomeric Al-species (especially Al-hydroxides, due to their high respiratory toxicity at pH 5.0–6.0) are most toxic to fish (DRISCOLL et al. 1980; LYDERSEN et al. 1990; HOWELLS et al. 1994; POLÉO 1995). By contrast, Al which is complexed to dissolved organic carbon (DOC) has low toxicity (LYDERSEN et al. 1990; PARKHURST et al. 1990). Although in the present study only total dissolved Al was measured, it can be deduced from the chemical characteristics of the test solutions that inorganic monomeric Al (Al_{im}) has prevailed. At low pH and high ionic strength, concentrations of polymeric Al are generally low (MILLER & ANDELMAN 1987; PLAYLE & WOOD 1990). Accordingly, inorganic monomeric Al species (Al^{3+}, Al-sulphates and -hydroxides) were predominant in minesoil solutions from an open-cast lignite mine (MONTERROSO et al. 1994). Furthermore, since levels of DOC in acidic post-mining lakes are low (ranging from <0.5 to 4 mg l^{-1}; KLAPPER & SCHULTZE 1995; KAPFER 1998; NIXDORF et al. 1998a), no DOC was added to the test solutions used in the present study. Hence, the new solutions added to the Petri dishes did not contain organically complexed Al. Between two replacements of the test solutions, some Al may have bound to substances released from the developing fish and the food organisms, and some Al may have precipitated, but new Al_{im} was added with the new test solutions.

Whereas Al concentrations of 0.1 and 0.2 mg l^{-1} had little effect on the early development of vendace, Al levels of 2.1 and 2.4 mg l^{-1} were, despite the high Ca content, clearly detrimental. High mortalities were already observed prior to hatch, i.e. during stages which are relatively tolerant to Al (BAKER & SCHOFIELD 1982; INGERSOLL et al. 1990; SAYER et al. 1991). Previous studies (MALTE 1986; WOOD & MCDONALD 1987; EXLEY et al. 1991) indicate that Ca does not provide a protection against the respiratory toxicity of Al. Moreover, the ionoregulatory toxicity caused by exposure to low pH and to Al is reduced but not prevented by high ambient Ca concentrations (WOOD & MCDONALD 1987; WOOD et al. 1990). Since the Al concentrations in the treatments A and B in our experiment were particularly high, the deleterious effect of acid and Al has apparently greatly exceeded the protective effect of Ca. Increasing sensitivity to both Al and low pH after hatch (INGERSOLL et al. 1990; SAYER et al. 1993) explains why the few embryos, which had hatched at pH 5.00 and 2.1 mg l^{-1} Al, died within a few days after hatch.

The reduced feeding activity of the larvae at pH 4.75 and low Al content (treatments C and D) compared to those in the respective treatments at pH 5.00 might be related to both pH (calculated average pH-values in the treatments 4.75C and D were significantly lower than those in the treatments 5.00C and D) and Al concentration (0.2 mg l^{-1} at pH 4.75; 0.1 mg l^{-1} at pH 5.00).

Increasing the Ca concentration from 111–117 mg l^{-1} to 233–256 mg l^{-1} had no influence on hatching and survival of vendace. In soft acid waters, Ca levels are often close to the lower tolerance limit of fish (ROSSELAND & STAURNES 1994). When Ca concentrations are very low (<4 mg l^{-1}), small increases in the Ca content lead to a significant increase of acid tolerance. However, when Ca levels are higher, the effects of a further increase diminish (BROWN 1982; FRENETTE et al. 1986; INGERSOLL et al. 1990). The lower Ca concentrations in our study correspond to those in River Spree, a lowland river with relatively hard water. Hence, a maximum protective effect of Ca might already have been reached in the treatments with lower Ca content, so that a further increase of the Ca concentration did not provide any additional protection from acid/Al toxicity.

Since a semistatic exposure system was used, pH increases between two replacements of the test solutions in the Petri dishes were unavoidable. Due to the buffering capacity of Al (BLOWES et al. 1994; GELLER et al. 1998) these increases in pH were higher when the Al concentration was low. The average pH-values in treatments 4.75C and D (where survival to the end of the experiment did not significantly differ from the control) were, however, still slightly lower than those in treatments 5.00A and B (where no embryos survived). Therefore, increased survival cannot be attributed to increased pH but was clearly related to the lower Al concentration.

As sensitivity to Al increases with age and, especially, with transition to branchial respiration (INGERSOLL et al. 1990; ROSSELAND & STAURNES 1994), it is not clear whether vendace exposed to pH 4.75–5.00 and 0.1–0.2 mg^{-1} Al would have survived to the juvenile stages. Moreover, further experiments using a flow-through system and in-situ exposure, respectively, are required to elucidate the contribution of Al to the mortality of vendace well after the onset of feeding and the impact of Fe precipitate on survival to hatch in Lusatian post-mining lakes.

To conclude, the results of the present study strongly suggest that Al is the key factor reducing the survival of vendace during embryonic and early larval development in reconstituted post-mining lake water. The negative effect of the elevated Al concentrations clearly exceeded the protective effect of the high Ca concentrations.

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Buchbesprechung

HEINONEN, P., ZIGLIO, G. & VAN DER BEKEN, A. (Hrsg.): **Hydrological and Limnological Aspects of Lake Monitoring.** XIX + 372 S., zahlr. Abb. u. Tab. Chichester: John Wiley & Sons, Ltd. 2000. Preis: Geb. £ 75.00. ISBN 0-471-89988-7.

Der Verlag John Wiley & Sons, Ltd. in Chichester hat mit der Herausgabe einer neuen Serie begonnen – *Water Quality Measurements Series*. Serien-Editor ist PHILIPPE QUEVAUVILLER, Brüssel. Das hier vorliegende erste Buch dieser neuen Serie hat das Ziel, Grundlagenwissen zur Überwachung von Seen zu vermitteln. Daneben soll es die Verantwortlichen für die Seen-Überwachung ermutigen, integrativ und umfassender als bisher vorzugehen. Das Schwergewicht wird dabei auf die Eutrophierung, die Versauerung und die Rolle der Schwermetalle mit all ihren Folgen gelegt.

Für die Beiträge dieses Buches zeichnen 34 Autoren verantwortlich, die überwiegende Mehrzahl von ihnen kommt aus Finnland. Der Grund dafür mag sein, daß gerade die nördlichen Seen sehr sensibel auf anthropogene Einflüsse reagieren. Die Nennung einiger Themen soll die außerordentliche thematische Breite des Buches demonstrieren: die Hydrologie von Seen; das „Watershed Simulation and Forecasting System (WSFS)"; die Modellierung von Einzugsgebieten; die Grundwasserbeeinflussung der Seen; Leaching (d.h. in diesem Fall Stickstoff-Ausspülungen aus Waldböden); chemische Stoffe, ihre Messung und Wertung im Monitorsystem; Phytoplankton und Wasserqualität, auch die Versauerung betreffend; toxische Cyanobakterien; die Nutzung der litoralen Algen für die Überwachung von Seen; Zoobenthos, Makrophyten und Seen-Überwachung; Fische und ihre Bedeutung für die Biomanipulation; Monitoring der faekalhaltigen Abwässer in finnischen Seen; Xenobiotika (besonders umfangreiche Darstellung); paläolimnologische Methoden und Ergebnisse im Hinblick auf frühere Belastungszustände der Seen; weitere Methoden (beispielsweise „remote sensing", d. h. die Messung der Strahlung aus Seen aus größerer Entfernung, z. B. auch von Satelliten; aber auch viele andere methodische Probleme, unter anderem die Frage der Standardisierung); die Vorstellung von Programmen und Organisationen (so z.B. das Eurowaternet-Programm, das auf nationalen Programmen basiert und über europäisches Gewässermonitoring informiert).

Der kurze Ausschnitt aus dem Themenspektrum zeigt die Reichhaltigkeit dieses Buches auf, das all denen, die mit der Seen-Überwachung und -Sanierung befaßt sind, wärmstens zu empfehlen ist.

W. SCHÖNBORN, Jena